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A Simulation-Based Performance Comparison between Flow Shops and Job Shops

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Abstract: It is well known in manufacturing that a flow shop usually outperforms a job shop for comparable products. This paper aims to understand the impact of routing variability on WIP inventory, lead time, and delivery performance. A perfect flow shop has no routing variability, with every part following exactly the same sequence of processes. A job shop, on the other hand, often has significant routing variability. In reality, there can be any degree of variability, from the perfect flow shop to a perfectly random routing in a job shop, or anything in between. This paper compares the performance of a perfect flow shop with a perfectly random job shop, aiming to keep all other factors influencing the performance as comparable as possible. The goal is to isolate the impact of routing variability on system performance.

Keywords: Flow Shop, Job Shop, Utilization, Delivery Performance, Lead Time

1 Introduction

The material flow in manufacturing can be arranged in two basic ways. In a flow shop, the processes are arranged in the sequence in which the material is processed. (Almost) all parts have the same sequence of processes. In a job shop, the processes are arranged by their function. The parts often have very different sequences of processes and hence very different material flows.

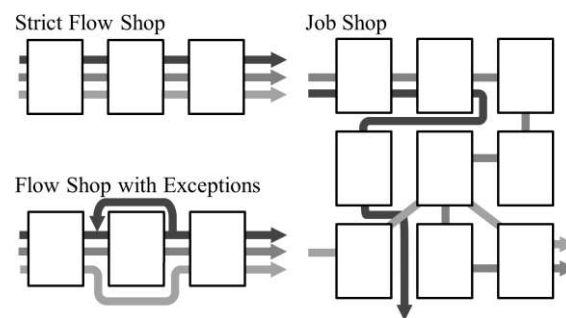


Figure 1: Illustrative example of a strict flow shop, a flow shop with exceptions, and a job shop

These differences in material flow make the management of a job shop much more challenging and complex than the management of a flow shop. As a result, the

performance of a comparable flow shop is usually vastly superior to the performance of a job shop. Figure 1 shows an illustrative example of the material flow in flow shops with or without exceptions and a job shop.

Much research has been done on the question of managing the material flow of a job shop. An exhaustive literature review would exceed the scope of this paper. An overview of such job shop scheduling approaches can be found at (Arisha, Young, and Baradie 2001) or (van Hoorn 2018). Swarm intelligence was also a popular approach in research (Gao et al. 2019), albeit not in industry. Nowadays, artificial intelligence and genetic algorithms are often employed in research, albeit its use in industry is still infrequent. See (Amjad et al. 2018) for an overview. There is also research on flow shop scheduling (González-Neira, Montoya-Torres, and Barrera 2017), albeit in a much smaller quantity as the problem is often less complex.

2 Relevance for Lean Manufacturing

One key concept in lean manufacturing is *flow*, often summarized as “*Flow where you can, pull where you can't*” (Roser 2021). The idea is to increase the share of time within the lead time where the part is improved and value is added to the part, and to reduce all non-value adding times, especially the waiting times. Flow shops are much easier to manage compared to job shops, which leads to much less fluctuations and variations in the material flow, which requires much less inventory to buffer said fluctuations, which in turn has much less inventory waiting. Overall, the flow is much better in a flow shop compared to a similar job shop.

Within this paper, we try to compare the behavior of a flow shop with the behavior of a job shop, keeping everything as similar as possible (number of processes, arrivals, cycle times, etc.), except for the routing of the parts. In the flow shop, all parts follow the same process sequence. In the job shop, all parts have a random sequence, but with the same number of process steps. Thus, we try to extract the effect of the process sequence variability onto the overall system performance. It would be difficult to create such a system in the real world, hence we used simulation software which allowed us a high level of control over all system parameters.

3 Simulated Systems

This paper that originated from a thesis (Ballach 2021) aims not to schedule but to compare the performance of flow shops and job shops. This comparison is for systems that are as similar as possible. The only desired difference was the routing of the parts through the system. For the flow shop, each part followed exactly the same process sequence.

Figure 2 shows the simulated flow shop system for 5 processes. There is an infinite supply and demand of parts. The processes all have exactly the same gamma distributed cycle time, with a buffer of capacity 10 between the processes. For consistency with the job shop, a buffer before the first process has also been added, even though this

buffer after an infinite supply will always be full and has no impact on the productivity but increases only inventory and lead time.

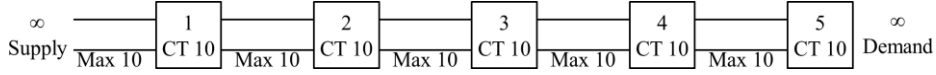


Figure 2: Flow shop system with 5 processes

The job shop system for 5 processes is also shown in Figure 3. Every process also has the same identical gamma distributed cycle time, with a buffer of capacity 10 in front of every process. The main difference is the routing, which is perfectly random. Every arriving part gets randomly assigned to one of the processes. After completion the part gets again randomly assigned. A counter keeps track of the number of iterations, and releases the part after a number of iterations that matches the number of processes.

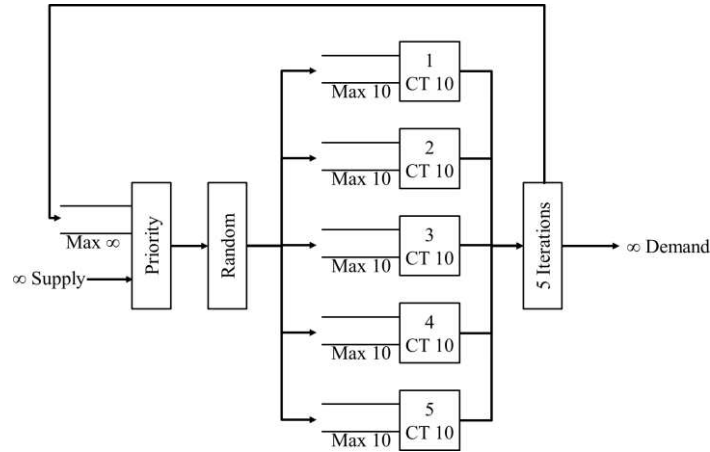


Figure 3: Job shop system with 5 processes

Besides the iterating random material flow there is another difference, which was necessary to make the system feasible. Parts in iteration have priority of new parts arriving. A queue in front of the prioritization holds iterated parts that cannot yet be assigned due to the queue of the target process being full. Hence this additional queue with infinite capacity is necessary to make the system feasible, but will increase the inventory and lead time.

To compare the effect of the size of the system, we created similar flow shops and job shops not only for 5 processes but also for 3, 10, 25, and 50 processes to model larger and smaller systems. A system with a single process was also simulated, although in this case the flow shop and the job shop systems are identical. As it is standard with simulations, we determined a suitable warm-up period and results-collection period to eliminate the behavior during the ramp-up of the system.

4 Comparison Results

4.1 Utilization

The utilization of the flow shop and the job shop for different number of processes is shown in Figure 4. The utilization of the flow shop was not significantly affected by the number of processes, and a system with 50 processes has almost the same utilization as a system with 3 processes.

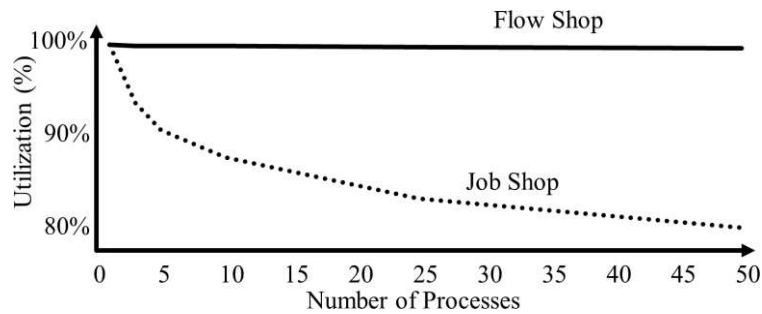


Figure 4: Comparison of utilization of flow shop and job shop

This, however, was not true for the job shop system. Increasing the number of processes in the system increased the randomness of the routing and decreased the utilization. For the largest system with 50 processes, the utilization was reduced to 79.9%, compared with an almost perfect utilization of 99.6% for the flow shop.

4.2 Line Takt

The line takt in Figure 5 shows a similar behavior. Since the line takt is measured as a time per part, its behavior is inverse to the utilization. The line takt is also the inverse of the throughput. All of the processes had a mean cycle time of 10 time units. With a near-perfect utilization the flow shop was able to complete a part almost every 10 time units. The job shop, however, suffered more and more as the number of processes increased. For the worst case with 50 processes, the job shop had a line takt of 1 part every 12.52 time units, where the flow shop completed a part every 10.04 time units.

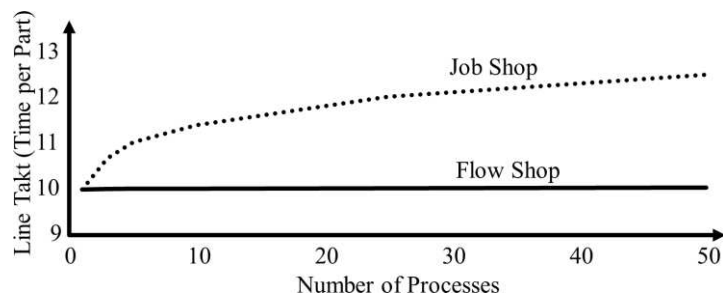


Figure 5: Comparison of line takt of flow shop and job shop

4.3 Inventory

Figure 6 shows the inventory of the flow shop and the job shop for different numbers of processes. As the number of processes increase, the buffer capacity increases as does the inventory.

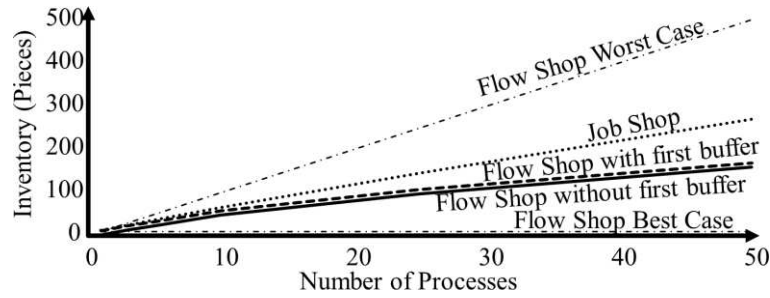


Figure 6: Comparison of inventory of flow shop and job shop

As explained above for Figure 2, the flow shop included a buffer in front of the first process for comparability, even though this buffer is always full and has no positive impact on the utilization or line takt, but increases inventory and lead time. Hence, in Figure 6 we show the inventory in the flow shop both with and without the first buffer.

The job shop shows a very linear increase, although the inventory increases slower than the number of processes. For 3 processes a job shop has in average 7.8 parts per process, whereas for 50 processes the average is 5.4 parts per process.

For flow shops the increase is significantly less, regardless if we include the first buffer or not. However, this depends heavily on the cycle time of the different processes. In our example all processes had equal cycle times. Due to random fluctuations, this caused the buffers to become emptier the further downstream they were. If the cycle times were different, the system would behave different. If the last process would be the bottleneck, then the flow shop would have much more inventory than the job shop. If the first process in the flow shop would be the bottleneck, then the flow shop would never have more inventory than the first buffer and the process inventory. The best case and the worst case are also shown in Figure 6. Please note, however, that in a worst-case situation with the bottleneck at the end, it would be possible to reduce buffers throughout the system without any impact on the utilization or line takt, but with a drastic improvement of the inventory and the lead time. Hence the extreme situations in the flow shop are not realistic examples.

4.4 Lead Time

The lead time is directly related to the inventory and the line takt. This relation is known as Little's law (Little 1961). Figure 7 shows the lead time for the flow shop and the job shop example. The flow shop extremes from Figure 6 are not included, since the line takt of the flow shop system and comparable job shop systems would also be impacted by the cycle times, and hence the lead time would also show a more complex behavior.

Yet, for the simulated systems the flow shop also has a significantly faster lead time than the job shop, regardless if we include the first buffer of the flow shop or not.

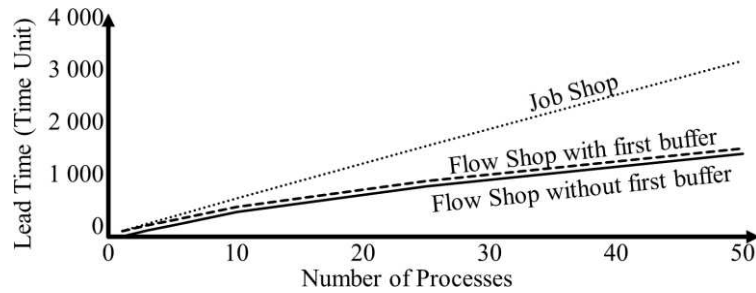


Figure 7: Comparison of lead time of flow shop and job shop

5 Summary

Overall, the flow shop performs much better than the job shop with respect to utilization, line takt, inventory, and lead time. Hence, it makes a significant difference if you have the same process sequence for all parts (flow shop) or if they differ (job shop). The utilization and the line takt can easily be 20% worse purely based on the process sequence variability.

This is, however, for an idealized system where only the routing of the parts differs. In the real world there may be additional differences. For example, the flow shop routing may not be as perfectly random as in this simulation, which would improve the behavior of the job shop.

However, there are many more effects which make the job shop behavior worse. For example, in this simulation it was always clear which job goes where next, and there was always 100% capacity available at every process. In reality, however, a job shop has much more confusion regarding the next job for a process, the next process for a job, or the moving around of operators among different processes to reduce idle times of the operators.

Overall, a job shop is almost always more difficult to understand and to manage, and in reality there will be more losses due to searching, waiting, or gathering information or tools. These losses also enable more mistakes, which generate subsequent losses. A flow shop will have much fewer problems of this type. Hence, it will be beneficial in many cases if the job shop could be transformed into a flow shop, making it easier to *flow* material and hence making it a leaner system.

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